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GIS-based Approaches to Catchment Area Analyses of Mass Transit

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1 Abstract

Catchment area analyses of stops or stations are used to investigate potential number of travelers to public transportation. These analyses are considered a strong decision tool in the planning process of mass transit especially railroads. Catchment area analyses are GIS-based buffer and overlay analyses with different approaches depending on the desired level of detail. A simple but straightforward approach to implement is the Circular Buffer Approach where catchment areas are circular. A more detailed approach is the Service Area Approach where catchment areas are determined by a street network search to simulate the actual walking distances. A refinement of the Service Area Approach is to implement additional time resistance in the network search to simulate obstacles in the walking environment. This paper reviews and compares the different GIS-based catchment area approaches, their level of detail and their strengths as applications in the planning process of mass transit.

Keywords: Catchment area, GIS, Mass transit, Public transportation, Railroad, Service area, Network search, Network Analyst, Time resistance

2 Introduction

A catchment area for mass transit can be defined as the vicinity of a stop or a station of a public transportation line. Moreover, this area is where most of the non-transferring passengers at the particular stop or station come from. In that way the catchment area can be viewed as the customer base for public transportation hence analysis of catchment areas can be useful in the planning of mass transit [1].

A catchment area is defined by geographical boundaries and analyses of catchment areas are, therefore, suitable in GIS. A catchment area analysis usually consists of two phases. The first phase is the determination of the geographical catchment area. This means defining the geographical boundaries of the catchment area. In GIS the first phase can be conducted through Buffer analysis and the distance that defines the size of the buffer can be determined through willingness to walk criteria. The second phase is the attachment of information regarding travel demand to the geographical catchment area. In GIS the second phase can be conducted by Overlay analysis and the information of travel demand can consist of number of inhabitants and workplaces. This article focuses primarily on the first phase of the catchment area analysis.

The simplest approach to GIS-based catchment area analyses is to use circular buffers as explained in section 3 “Circular Buffer Approach”. A more detailed and realistic approach is to use searches in street network in order to implement the actual walking distances of the feeder traffic to mass transit stations. This approach is especially suitable for more detailed analyses of catchment areas e.g. improving accessibility to stations. However, this approach has some uncertainties that mainly concern the applied street network and the desired level of detail. The approach is called Service Area Approach and is described in section 4 “Service Area Approach”. The Service Area Approach can be refined to handle even more detailed investigations of accessibility to stations that incorporates obstacles in the walking environment. This is done by implementing time resistance in the network search. This refinement is described in section 5 “Time resistance in catchment area analyses”.

Beside from describing the different GIS-based approaches to catchment area analyses, this article also makes relevant comparison between the different approaches and reviews their applied use in the planning of mass transit.

3 Circular Buffer Approach

The simplest and most common used approach to make catchment areas of a station is to consider the Euclidean distance from the station. This simple approach has in some years been used at the Technical University of Denmark (DTU) to examine and optimize stop locations along new railroad and Light Rail Transit lines (e.g. [2]). Often the level of detail in the method has been increased by dividing the catchment area into different rings depending on the distance to the station. By applying weights for each ring it is possible to take into account that the expected share of potential travelers will drop when the distance to the stop is increased [3].

Figure 1 shows a circular catchment area for Noerrebro urban rail station in Copenhagen. The catchment area is divided into an inner and an outer ring which is a commonly applied division and referred to as the primary and secondary catchment area respectively.

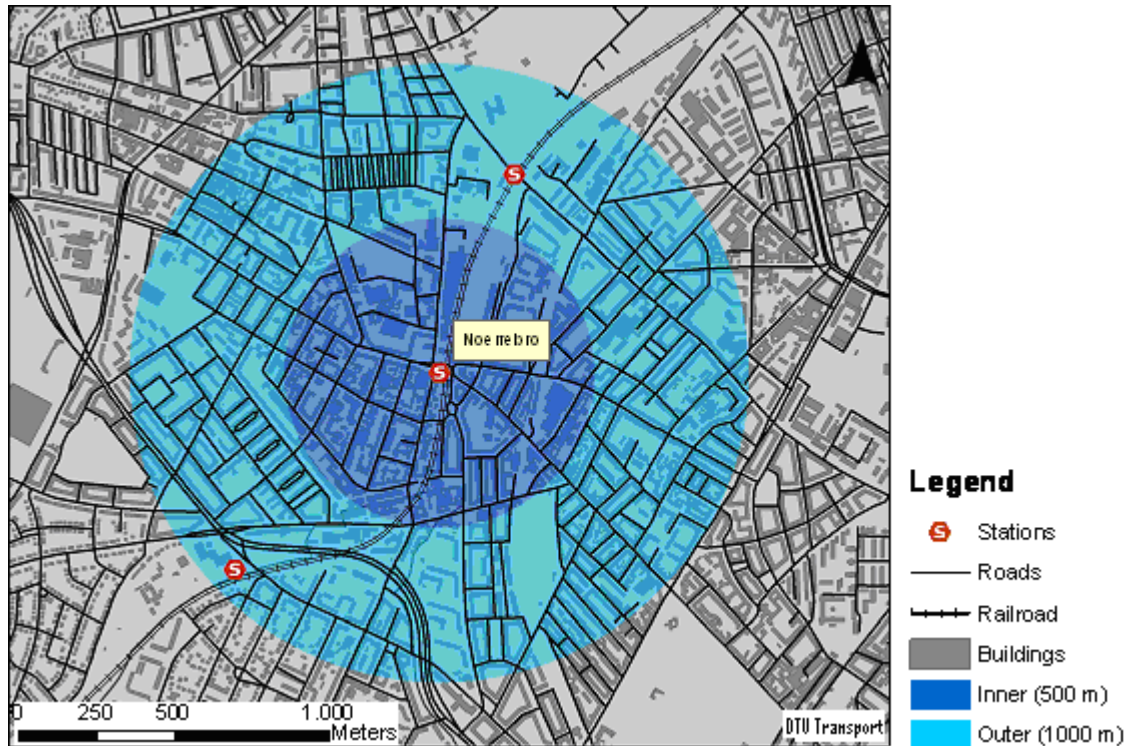


Figure 1 – Circular catchment area of Noerrebro Station in Copenhagen

3.1 Limitations of the Circular Buffer Approach

The Circular Buffer Approach is a simple and fairly good approach to examine catchment areas for stations but it does not take the geographical surroundings into account. In most cases, the actual walking distance to/from the station is longer than the Euclidean distance since there are natural barriers like rivers, buildings, rail tracks etc. This limitation is often coped with by applying a detour factor that reduces the buffer distance to compensate for the longer walking distance. However, in cases where the length of the detours varies considerably within the stations surroundings, this solution is not very precise. Furthermore, areas that are separated completely from the stations e.g. by rivers might still be considered as part of the stations catchment area [4].

3.2 Applied use of the Circular Buffer Approach

Since the Circular Buffer Approach has some limitations it is best suited for overall analyses of catchment areas. This could for instance be analyses of whole mass transit lines in order to compare different alignments and/or stop locations. It could also be used

in the initial phase of placing stations on a new railroad line. For this purpose a travel potential graph as seen in figure 2 can be useful.

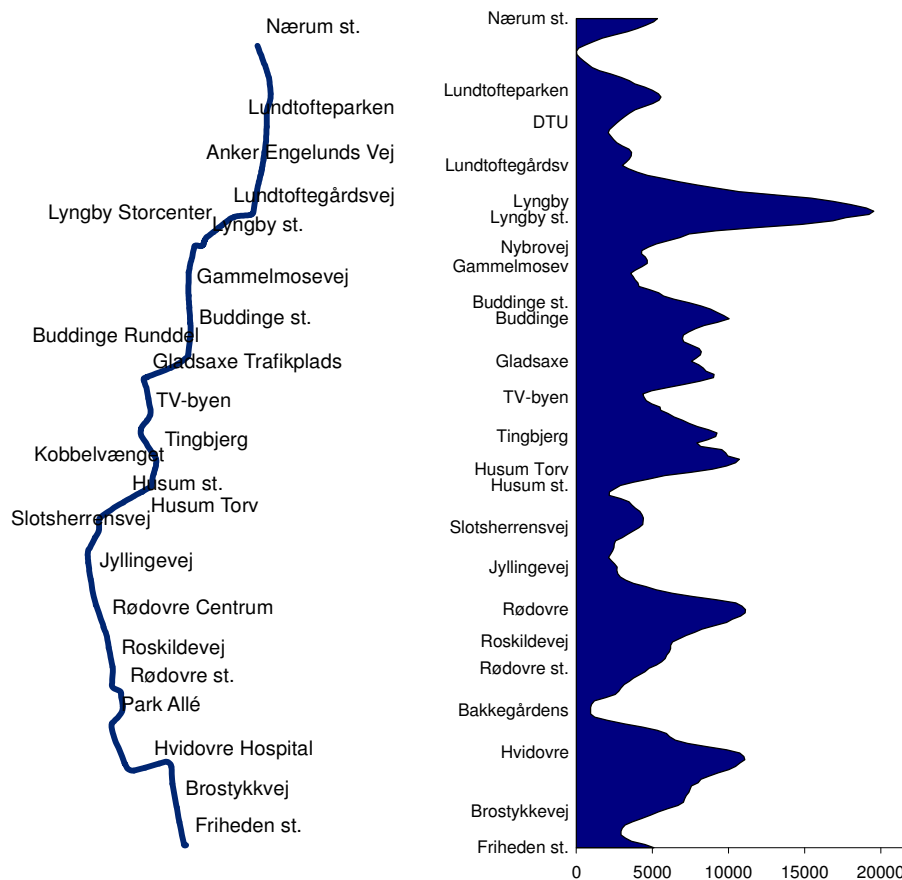


Figure 2 – Travel Potential Graph for a proposed Light Rail Transit line in Copenhagen

The travel potential graph has been created by using the Divide function in ArcGIS to split the polyline representing the alignment of the mass transit line and executing buffer analysis for every X meters (in the figure every 50 meters). Each buffer is then intersected with underlying travel demand data. In that way the travel potential graph illustrates the travel potential along the total length of a proposed alignment of a new mass transit line and thereby identifies areas along the alignment where the customer base can support a station.

4 Service Area Approach

A more detailed approach to GIS-based catchment area analyses is the Service Area Approach. This approach utilizes the fact that feeder traffic to stations in cities often is restricted to streets and pathways. Therefore, a search in a street network can give more realistic catchment areas. To make Service Areas the Network Analyst extension to ArcGIS can be used. The Service Area function calculates buffers by determining a point in each branch of the network based on an impedance of each link and then interpolating

these branch points to a polygon. The principle of the Service Area Approach can be viewed in figure 3. For more information about the methodology see [5].

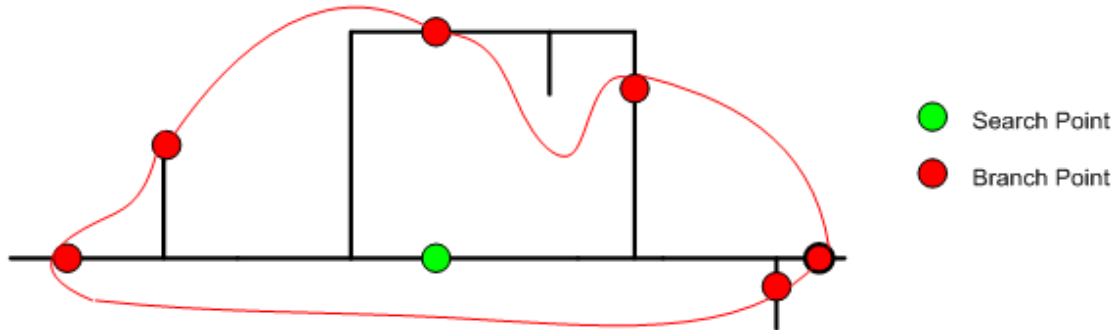


Figure 3 – Principle of the Service Area Approach

4.1 Comparison with the Circular Buffer Approach

Where the Circular Buffer Approach neglects all physical obstacles in its buffers the Service Area Approach prevent inaccessible areas because of physical barriers to be included in the Catchment area. This is evident on figure 4 where catchment areas for Christianshavn metro station in Copenhagen has been performed using both the Circular Buffer Approach and the Service Area Approach. First of all it can be seen how the shape of the calculated Service Area buffer corresponds to the street network around it. It can also be seen that some of the areas which in the Circular Buffer Approach is considered within the catchment area are excluded in the Service Area approach. This is due to the limited possibilities for crossing the canals and corresponds to the fact that people in these excluded areas do not have good access to Christianshavn metro station.

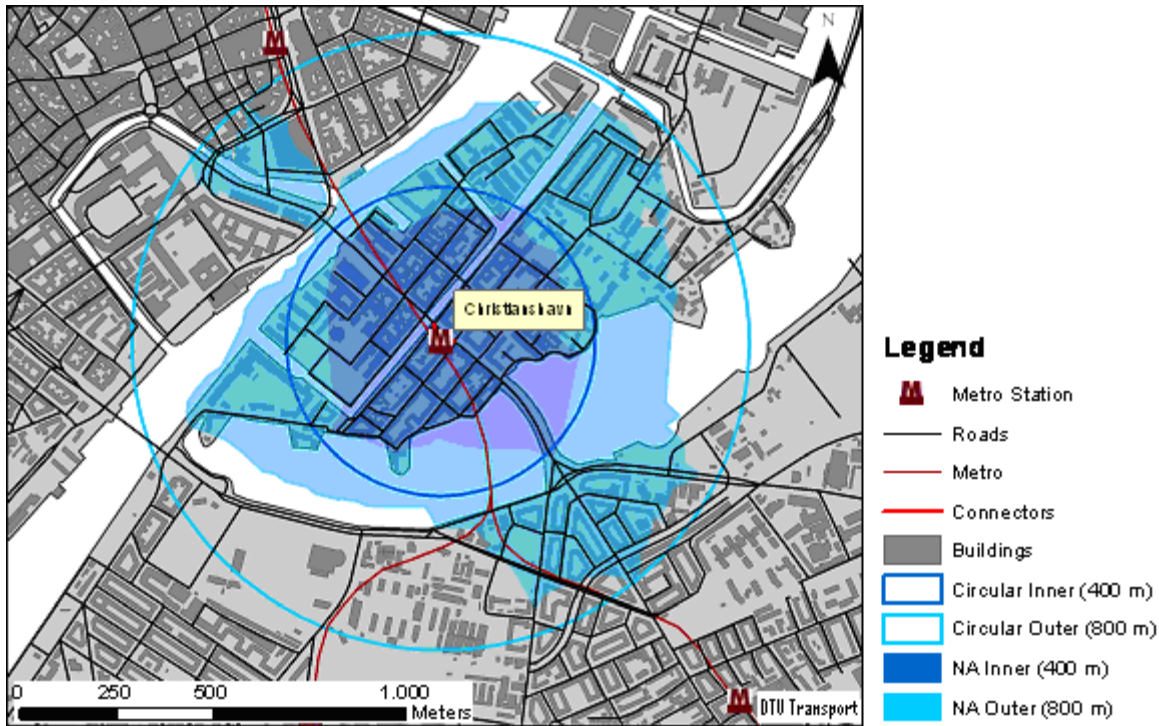


Figure 4 – Catchment area of Christianshavn metro station in Copenhagen – Circular Buffer Approach and Service Area Approach

Another issue that also can be seen on figure 4 is that the Circular Buffer Approach overestimates the catchment area compared to the Service Area Approach. This is a consistent issue since it is not possible to walk as the crow flies in an urban environment. This can partly be handled by applying a detour factor on the buffer distance of the Circular Buffers. However, the detour factor depends on the layout of the streets and pathways together with the geographical barriers in the stations surroundings. The variation of the area of the two methods and the proportion is shown in table 1 (based on [5]).

Station	Area (600m Circular buffer)	Area (600m Service Area buffer)	Proportion
Bispebjerg	1,130,970 m ²	419,879 m ²	0.37
Charlottenlund	1,130,970 m ²	728,505 m ²	0.64
Christianshavn	1,130,970 m ²	663,117 m ²	0.59
Dybboelsbro	1,130,970 m ²	596,301 m ²	0.53
Hellerup	1,130,970 m ²	855,473 m ²	0.76
Jaegersborg	1,130,970 m ²	652,961 m ²	0.58
Noerrebro	1,130,970 m ²	842,050 m ²	0.74
Sjæloer	1,130,970 m ²	715,351 m ²	0.63
Svanemoellen	1,130,970 m ²	703,817 m ²	0.62
Sydhavn	1,130,970 m ²	654,828 m ²	0.58

Table 1 – Proportions between the sizes of catchment areas of different stations in Copenhagen calculated with Circular Buffer Approach and Service Area Approach [5]

Table 1 shows that the proportion between catchment areas of the Circular Buffer Approach and the Service Area Approach varies from 0.37 to 0.76. This variation indicates that it is impossible to apply one general detour factor to improve the Circular Buffer Approach (also [6] shows this tendency), why a method like the Service Area Approach is considered to be more realistic.

4.2 Uncertainties in the Service Area Approach

For the Service Area Approach to be as realistic as possible it is important with a high level of detail in the street network used in the Network Analyst search. GIS networks are often based on streets but since the feeder traffic to stations predominantly consists of walking (and in some cities cycling) it can also use pathways and short cuts. Therefore, it is very important to include these pathways and short cuts in the street network where the Network Analyst search is performed otherwise the catchment area might turn out smaller than it actually is.

Another issue by using Service Area street network search is double digitized streets and roads. In GIS networks, streets can be double digitized with a link for each direction of traffic. It is rarely used on ordinary two-lane roads because the lanes are not separated and modeling links can be bi-directional. However, in street networks double digitized roads are often used for roads with four lanes or more. Primarily when the directional lanes are physically separated; for example by a central grass verge which is the case on many four-lane roads. This can be a problem in the Service Area street network search. If a four-lane street has a central grass verge it can be used as an island for crossing pedestrians (or cyclist). This means that soft road users can cross the street in a straight line. When using the Service Area Approach, the searched route has to follow the network. Therefore, the crossing of double digitized streets has to be done through crossing links; possibly forcing the search route on a practical detour as sketched in figure 5.

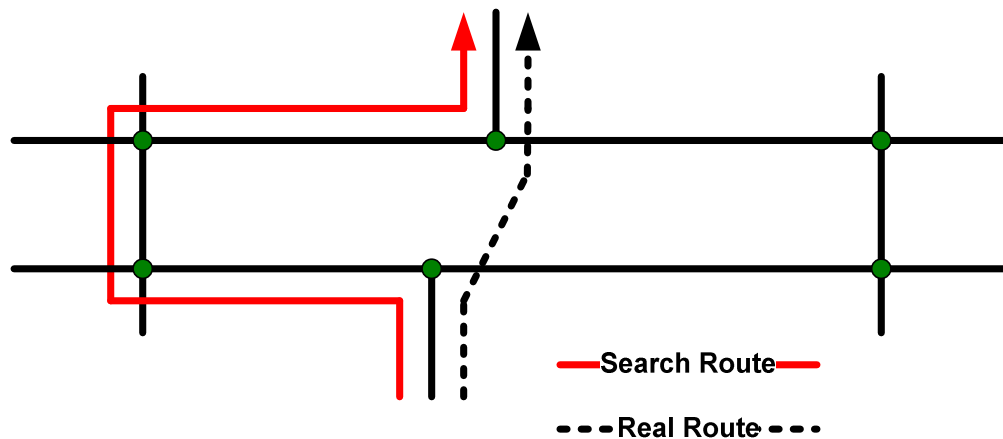


Figure 5 – Service Area network search dilemma on double digitized roads

In such cases the outcome will be a smaller catchment area than the actual catchment area.

However, it is important with knowledge of the implemented double digitized streets. Many four-lane streets are indeed separated by a central grass verge offering good crossing possibilities for the soft road users. But some four-lane roads actually have the directional lanes separated by a central fence or crash barrier making soft road user crossing almost impossible.

If the network is connected so that crossing of double digitized streets is possible; the catchment area calculated by the Service Area Approach might increase as seen on figure 6. Strandboulevarden near Nordhavn urban rail station in Copenhagen has a central grass verge and is relatively easy to cross for soft road users [4].

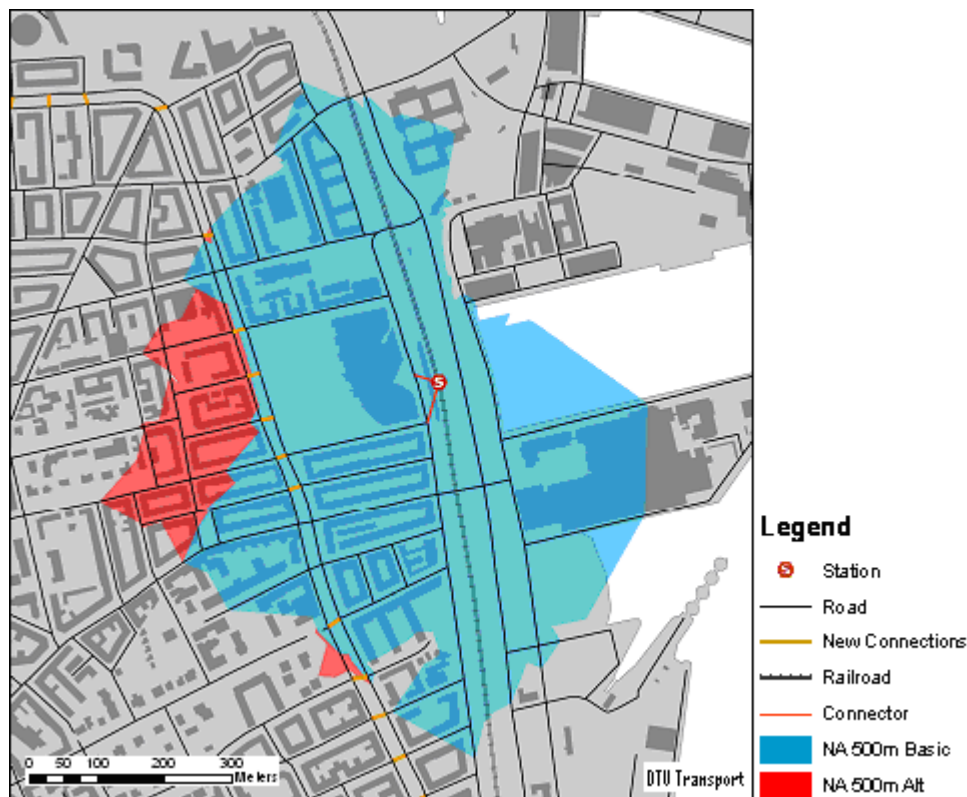


Figure 6 – Crossings of a double digitized road increase the catchment area of Nordhavn station in Copenhagen

When using the Service Area Approach it is important to minimize the uncertainties by applying a high level of detail of the used datasets. If this is not done the Service Area Approach may not prove more detailed and realistic than the Circular Buffer Approach.

4.3 Applied use of the Service Area Approach

The Service Area Approach can – like the Circular Buffer Approach – be suitable for superior investigations of mass transit e.g. investigations of whole alignments and station

positioning via the travel potential graph if the level of detail of the used datasets supports it. However, since the Service Area Approach is a more detailed approach than the Circular Buffer Approach it is useful for more detailed analyses of catchment areas. The Service Area Approach is especially suitable for investigations of improvements in accessibility to stations. This could be upgrading of the street network surrounding a station making better connections from the surrounding area to the station for example by establishing a bridge or a tunnel to cross barriers like major roads, railroads or rivers. It could also be investigations of how to make entrances to station platforms and how many to have.

Figure 7 shows the effect of the catchment area calculated with the Service Area Approach with and without a pedestrian bridge across railroad tracks at Nordhavn urban rail station in Copenhagen¹.

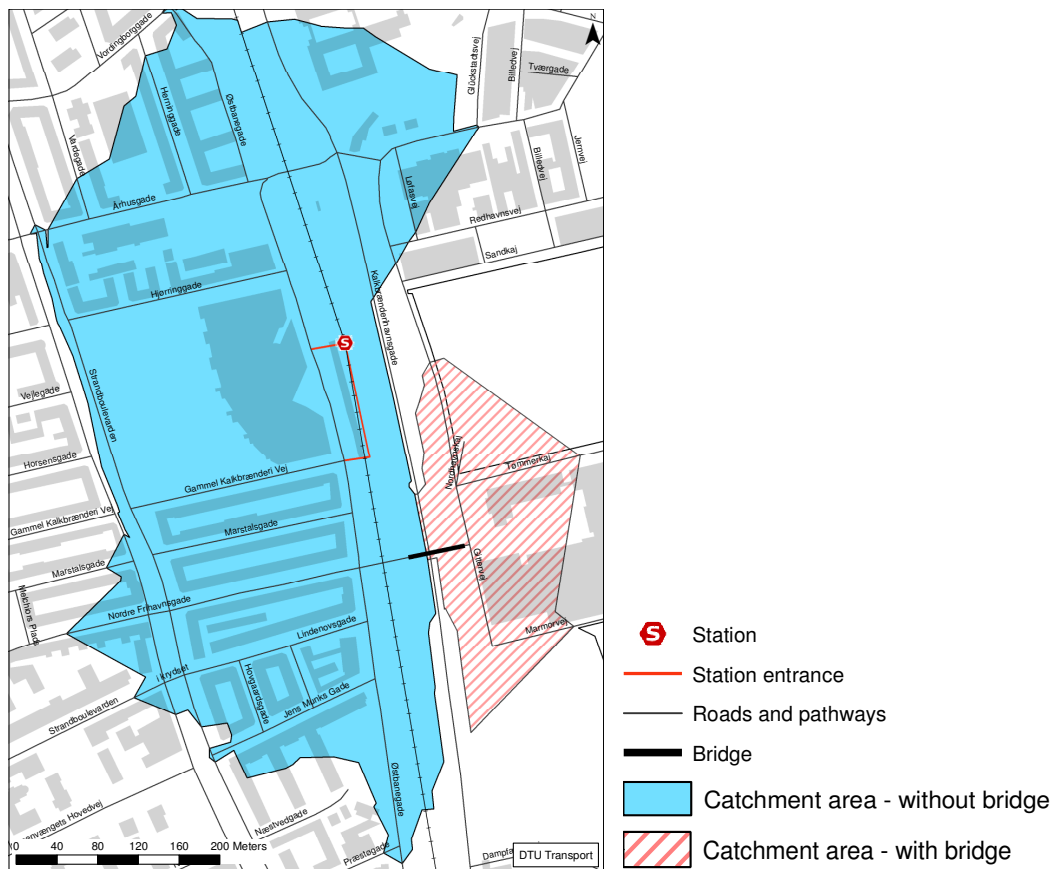


Figure 7 – Catchment area calculated by the Service Area Approach with and without a bridge to cross railroad tracks at Nordhavn Station in Copenhagen

Figure 7 shows that the catchment area at Nordhavn Station is much larger with the bridge across the railroad at Nordhavn Station.

¹ This pedestrian bridge exists today but it has been temporarily removed in the past due to reconstructions of tracks and roads in the area

Such increments of catchment areas caused by improvements in the street network in the surroundings of a station are possible to examine through the Service Area Approach while the Circular Buffer Approach will not show any changes in the catchment area [4].

5 Time resistance in catchment area analyses

In the previous presented catchment area analyses with the Service Area Approach the size and shape of the catchment area have been determined by walking distance to/from the station. However, when using an average walking speed (here 80 meters/minute as [6] suggest), time can be implemented instead of distance as a resistance variable in the street network search. By doing so, the implementation of specific resistance in the network search such as resistance for crossing stairways can be eased.

5.1 Time resistance in stairway crossings

Maps are (most often) 2-dimensional. This means that the catchment area analyses do not take the time it takes to cross stairs into account but “only” the 2D walking distance. In case of e.g. metro stations, the time to access the platform is significant (in Copenhagen it is measured to take about 1.5 minutes from street level to platform level 20 meters below although the 2D distance is zero or only few meters). This extra access time may be a significant part of the total access time to the station, and should, therefore, preferably be included in the catchment area analyses.

Using the Network Analyst Service Area tool for ArcGIS, additional time resistance can be added to nodes in street networks (here nodes representing stairways). This results in smaller, but more realistic catchment areas compared to both the Circular Buffer Approach and the Service Area Approach without additional time resistance [1].

Figure 8 shows the effect of additional time resistance for stairway crossing in the Service Area Approach with the pedestrian bridge across the railroad tracks at Nordhavn urban rail station in Copenhagen.

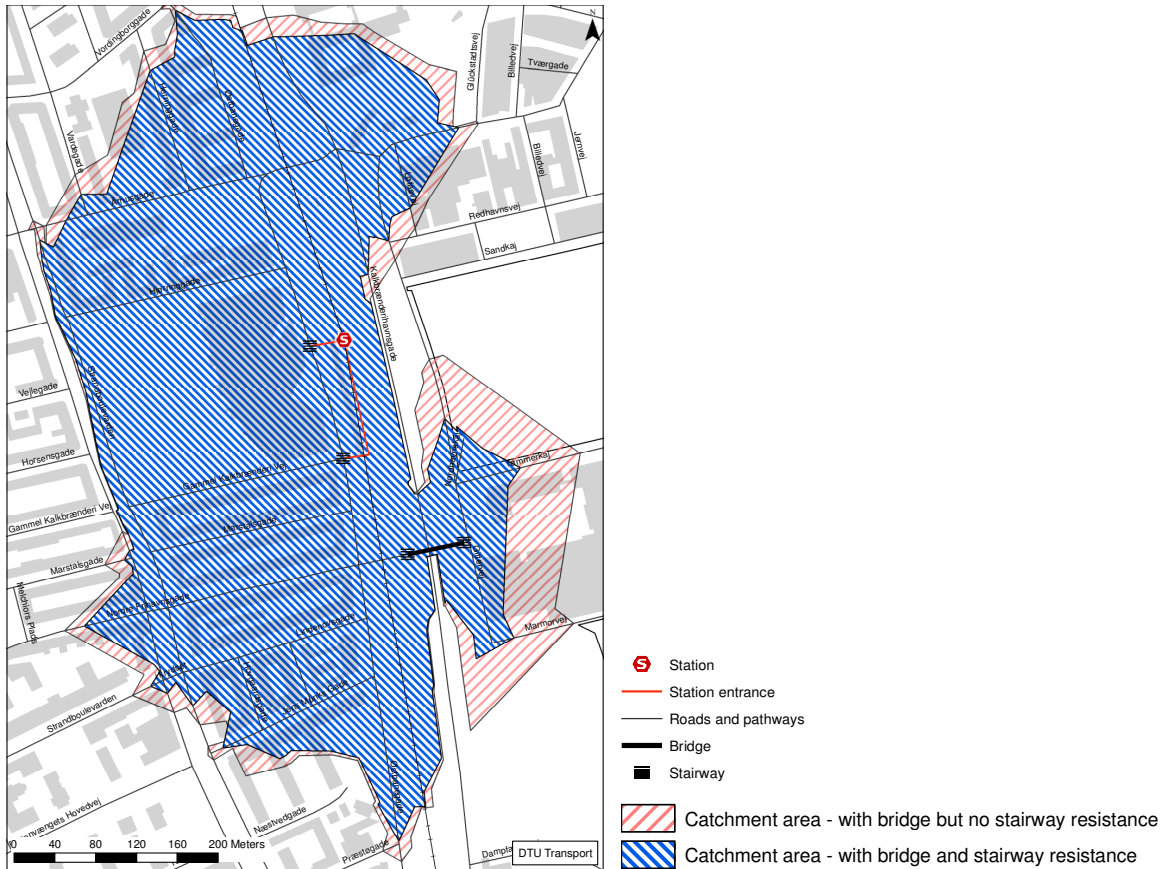


Figure 8 – Catchment area calculated by the Service Area Approach with and without stairway resistance at Nordhavn Station in Copenhagen

The case example in figure 8 is the same as used in figure 7 at Nordhavn station. But now it can be seen that using the pedestrian bridge actually means crossings of stairway steps just as the entrance to the elevated station also means crossing stairs. When implementing an assumed time resistance (here 15 seconds) for crossing the stairways to the platform and the bridge, the catchment area is decreased as viewed in the figure 8.

When using the time resistance refinement of the Service Area Approach it is also possible to implement other resistance variables than stairway crossing to the network search. This could be issues such as road crossings or other traffic conflict points. In cities with hilly terrain a resistance for crossing slopes could also be implemented, e.g. by adding an additional time resistance every time a network link crosses a contour line. All approaches are relatively easy to implement in GIS-based catchment area analyses [1].

5.2 Applied use of time resistance in stairway crossings

Due to the time resistance in stairway crossing, the Service Area Approach can be used to examine catchment areas of different alternatives for public means of transportation more detailed. E.g., it is possible to examine the difference in catchment area of an underground metro line and a Light Rail Transit line at street level.

Figure 9 illustrates how the stairway resistance impacts the catchment area of an underground station compared to a ground-level station. The Case example is Noerrebro Runddel, a central place in Copenhagen where both an underground solution (Metro) and a ground-level solution (Light Rail Transit) has been proposed for the future [7]. Access time from street-level to platform level is set to 1.5 minutes for the underground station proposal. Whereas the ground-level station proposal does not have any access time applied since it is already at street level. This results in a larger catchment area for the ground-level station proposal.

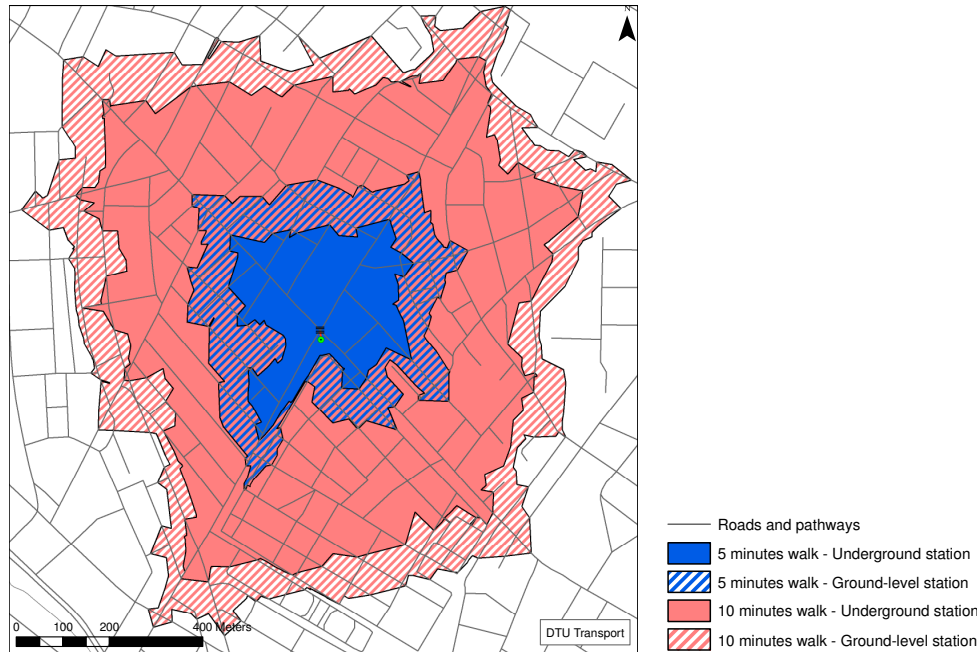


Figure 9 - Catchment area of an underground station vs. a ground-level station – proposal at Noerrebro Runddel in Copenhagen

By applying different time resistances to the map, it is also possible to examine the catchment area for different groups of potential travelers – e.g. young people, elderly people and people with strollers. In this way it is possible to evaluate whether it is favorable/necessary to improve the access to public transport for some groups of potential travelers. However, conducting this kind of analyses requires detailed data about both the infrastructure network and the time resistances of different access paths and entrance points – e.g. lifts and stairs [1].

In the case examples of time resistance in stairway crossings from figures 8 and 9, only measurable additional time use has been included. The time it takes to cross stairways depends on the number of steps and can relatively easy be measured and implemented. However, studies of walking often also include an experienced resistance due to the effort of climbing stairs and general inconvenience of crossing stairways that is an addition to the actual time use resistance (e.g. [8]). This experienced resistance might be correlated to the actual time resistance in a way that results in higher values for disabled, elderly people or people with strollers. If experienced resistance was to be implemented in this study, the result would be even smaller catchment areas [1].

6 Conclusions

When using GIS-based catchment area analyses the objective of the analysis and the desired level of detail must be the decisive factor for choosing the precise approach.

The Circular Buffer Approach is a simple, but straightforward method to implement. It suits fine for investigations of whole mass transit lines, alternative alignments and initial placing of stations e.g. using travel potential graphs. The Service Area Approach provides more detailed and realistic catchment area analyses since it is based on the actual feeder routes to public transport. The approach is also suitable for examination of improvements of accessibility to mass transit e.g. improvements in the streets and pathways surrounding stations or entrances to station platforms. The Service Area Approach can be refined by implementing time as a resistance element in the network search. Thus additional time resistance in certain designated points of the network like stairways can be implemented in order to simulate the time it takes to cross stairs. This can be favorable for investigations of special conditions in connection to access paths and entrances to stations, e.g. the impact of crossing many stairs to get to the station platform and it can be suited to different user groups.

In general, GIS-based catchment area analyses can be a useful decision support tool for planning of mass transit lines, station positioning and studies of accessibility to stations. The level of detail varies from simple circular buffer approaches to more complex approaches taking barriers and travel time into account. The approach and the level of detail depend on the datasets available.

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